ICCEPM 2022
The 9th International Conference on Construction Engineering and Project Management
Jun. 20-23, 2022, Las Vegas, NV, USA

Productivity Analysis of Spray Task in an International Airport

Krishna P. Kisi[1*] and Rujan Kayastha[2]

[1] *Department of Engineering Technology, Texas State University, San Marcos, TX 78666, USA,* E-mail address: kpkisi@txstate.edu
[2] *Department of Engineering Technology, Texas State University, San Marcos, TX 78666, USA,* E-mail address: r_k162@txstate.edu

Abstract: The objective of this study is to analyze the productivity, efficiency, and factors affecting the productivity of a spray task from an international airport project. The study is focused on the productivity analysis of the Subcontractor whose job was to supply and apply sprayed-applied fire-resistive material (SFRM) on steel members to achieve the necessary fire ratings on the building structures of the Hamad International Airport, Qatar. The study analyzed the productivity of the four sprayer teams who completed the task at three locations and three areas of the airport. The study found that the productivity of the individual team observed during the SFRM spray task was not only different but was also observed different when they worked at varying floor heights where different factors affecting productivity were predominant. The study found that the efficiency was lowest (47.32%) when the spray team had to work at second-floor heights and factors affecting productivity such as limited accessibility for material movement and lifting, site congestion, lack of continuity of operation due to priority areas and frequent re-handling of machines and tools were present. Besides, the factors such as adverse weather conditions and sub-trades interference affected productivity at all locations. The findings show that productivity depends on multiple factors and those factors need to be identified and addressed to improve productivity. The findings also show that the estimated efficiency was hard to achieve but possible since Team 4 had 97% efficiency on the first floor of the airport.

Keywords: Productivity, Efficiency, Factors affecting productivity

1. INTRODUCTION

The Bureau of Labor Statistics in the United States defined productivity as the real output per hour worked [1]. Economists defined labor productivity as the ratio of total product output to total labor input [2] or simply the ratio of output to input [3]. Park [4] outlined the two forms of productivity: the first form—i.e., output/input—appears widely in the construction industry and the existing literature; the second form—i.e., input/output—usually applies to estimations. Yi and Chan [5] explored the implications of the different definitions of construction labor productivity and concluded that hourly output provided the most reliable measurement of productivity for construction activities. There is no consensus on which ratio (output/input or input/output) defines productivity, which explains why the term lacks a standard definition [6]. For this reason, the current paper uses daily output as an appropriate unit of measurement relevant to the tasks performed in the research study for productivity analysis.

The objective of this study is to analyze the productivity of a spray task from an international airport project because of the reasons such as the nature of the task to conduct productivity analysis, and data size collected from the project. In addition, the study focuses on the efficiency of the spraying task and the factors affecting the loss of productivity of the sprayers. The study analyzes the productivity and efficiency data of the Subcontractor whose job was to supply and apply sprayed-applied fire-resistive material (SFRM) on steel members to achieve the necessary fire ratings on the building structures of the Hamad International Airport, Qatar.

2. LITERATURE REVIEW

Liberda and colleagues [7] stated that many factors involved in the process of construction have changed over time and productivity cannot be easily judged by the same data or information that was documented a decade or more ago. Song and AbouRizk [8] states "the current practice of labor productivity estimation relies primarily on either published productivity data or an individual's experience. Kisi and his colleagues introduced a concept of estimating optimal productivity as a way of benchmarking productivity to accurately estimate productivity at a labor-intensive construction operation [9,10,11].

A multitude of factors impact labor productivity [3, 12, 13, 14]. For example, Rojas and Aramvareekul [3] indicated that management systems and strategies had the greatest influence on labor productivity, followed by manpower, industry environment, and external conditions. Dai et al. [15] identified the most significant factors based on workers' perception of productivity performance. They determined that significant factors affecting craft workers' daily productivity included materials, tools, and equipment that were manage at the jobsite.

Below are the major factors found in literature that are relevant to this research study. These factors are grouped together based on their close affinity [10]. Four of the affinity groups relevant to this study are (a) Management Factors: factors such as inadequate supervision, management control/ project team, incompetent supervisors, inspection delays, overstaffing, and management practices [10, 14, 15, 16, 17, 18], (b) Site Conditions: factors such as site access, site layout, congestion/interferences, and material handling [10, 12, 19, 20], (c) Scheduling issues: such as schedule acceleration, overcrowding and/or overmanning, scheduled overtime, shift work, and out-of-sequence work [2, 10, 15, 18], and (d) Labor characteristics: such as labor/manpower, quality of craftsmanship, absenteeism, fatigue and health issues [3, 11, 15], craft turnover, skills, experience, motivation, and manpower shortages [3, 10, 16, 17, 20]. But many research lacks job tracking of labor output including supervisor efficiency based on daily basis, which is the fundamental element for productivity analysis. This paper fills that gaps.

3. DATA COLLECTION

This study collected data from the construction of the passenger terminal complex of the Hamad International Airport, formerly known as the New Doha International Airport, in Qatar. The Subcontractor's responsibilities included the supply of materials, supply of skilled authorized personnel, transportation, customs clearance, and all necessary fireproofing equipment and consumables. The Subcontractor provided fire protection to all the structural steel members of approximately over 1 million square meters (over 10.7 million square feet) and substantially completed the main scope of their work in April 2012 with the total value of QAR 83.32 million (the US $22.88 million) [21].

The analysis focuses on the productivity data from the four Sprayer teams involved in the project. Each sprayer team included one skilled sprayer, one machine operator, and two helpers. The data was collected from three different locations such as Concourse A, Concourse C, and Main Terminal Building (MTB) of the airport project as shown in Figure 1.

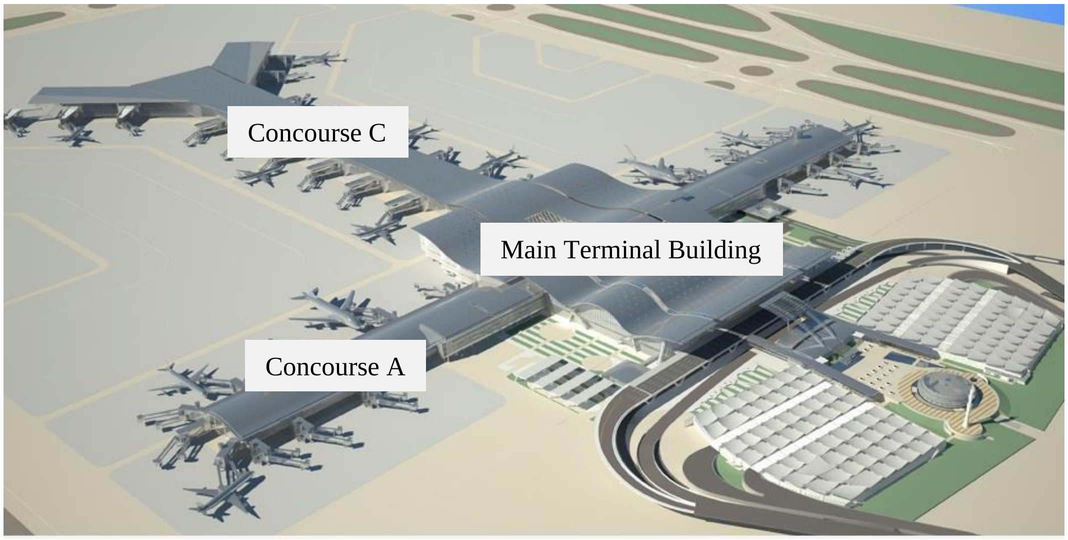

Figure 1. Hamad International Airport (Source: https://worldairlinenews.com/tag/hamad-international-airport/)

The data included productivity measurements from three different areas of the project. Figure 2 shows the spray work at the first floor (Figure 2(i)) of the Concourse A, second floor (Figure 2(ii)) of the Concourse C, and skylight area (Figure 2(iii)) of the MTB.

i. First Floor ii. Second Floor iii. Skylight Area

Figure 2. Spray task at different areas

4. RESULTS AND DISCUSSION

The productivity of Team 1, Team 2, Team 3, and Team 4 are shown in Table 1. Besides, Table 1 shows the productivity measurement of the teams at three different areas such as the first floor, second floor, and skylight area located at three different locations such as Concourse A, Concourse C, and MTB.

In Table 1, the productivity of each team was measured based on how many bags of Cafco 300/400 SFRM were sprayed per day. Since the approximate coverage of Cafco 300 / 400 SFRM is 46 to 50 square feet per bag (20kg) at the rate of 15mm thickness, it is easy for supervisor as well as the sprayer to record no of bags sprayed and approximate area covered instead of measuring the applied surface of various steel members direct in the site. The productivity measurement was then summed per week. Table 1 shows productivity data per week for four weeks measurement period. Since the weekly productivity data was different, the average productivity of each team was calculated based on the total number of SFRM bags sprayed divided by the total number of days worked for four weeks. For example, Team 1 sprayed 477 bags of SFRM in 12 days and thus their productivity was 39.75 bags of SFRM per day. Similarly, the average productivity of each team at different locations and areas was calculated and tabulated in Table1.

Table 1. Productivity measurement of Sprayers

Location	Area	Sprayer	Number of Bags of SFRM Sprayed Per Week				Total Number of Bags	Total Number of Days	Average Number of Bags Per Day
			1st week	2nd week	3rd week	4th week			
Concourse A	First Floor	Team 1	92	144	201	40	477	12	39.75
		Team 2	173	97	134	19	423	13	32.54
		Team 3	0	37	104	22	163	4	40.75
		Team 4	151	94	58	35	338	7	48.29
Concourse C	Second Floor	Team 1	48	65	0	0	113	6	18.83
		Team 2	158	116	27	0	301	11	27.36
		Team 3	75	107	0	0	182	8	22.75
		Team 4	151	94	12	0	257	10	25.70
Main Terminal Building	Skylight Area	Team 1	77	123	250	35	485	14	34.64
		Team 2	113	121	111	21	366	12	30.50
		Team 3	0	52	115	32	199	6	33.17
		Team 4	134	98	85	55	372	11	33.82

Table 2 shows the calculation of the efficiency of each teamwork. Each team efficiency was calculated as a ratio of their average actual productivity to the estimated productivity of the Subcontractor. The Subcontractor had estimated productivity for SFRM work to be 50 bags of SFRM per day which was based on their historical averages. Therefore, Team 1 efficiency was 80% on the first floor of Concourse A. Similarly, Team 2 had 65% efficiency, Team 3 had 82% and Team 4 had 97% efficiency compared to their historical productivity.

Besides, each team's efficiency, the study also calculated the efficiency of the supervisor to see how different their efficiency will be based on the location and area where they spray SFRM. Each supervisor along with his team were given a target of spraying more bags maintaining design thickness and quality at reduced wastage on daily basis. The efficiency of the supervisor was evaluated once the target was meet based on no of bags. The output was used later for Supervisor’s promotion, salary increment or awards. The efficiency of the supervisor was based on the average efficiency of the four sprayer teams in a particular location. For example, the supervisor overseeing the spray job at Concourse A had 80.66% which was calculated based on the average of the efficiency obtained by the four teams in that location. The efficiency of the sprayers and the supervisors observed on the second floor were very low and about 50% of the estimated efficiency. Similarly, the efficiency at the skylight area was about 66% of the estimated efficiency which is higher than the team's efficiency working at the second-floor height but less than their efficiency achieved working at the first floor.

Table 2. Productivity and efficiency measurement of Sprayers

Location	Area	Sprayer	Average Productivity (bags/day)	Estimated Productivity (bags/day)	Sprayer Efficiency	Supervisor Efficiency
Concourse A	First Floor	Team 1	39.75	50	80%	80.66%
		Team 2	32.54	50	65%	
		Team 3	40.75	50	82%	
		Team 4	48.29	50	97%	
Concourse C	Second Floor	Team 1	18.83	50	38%	47.32%
		Team 2	27.36	50	55%	
		Team 3	22.75	50	46%	
		Team 4	25.70	50	51%	
Main Terminal Building	Skylight Area	Team 1	34.64	50	69%	66.06%
		Team 2	30.50	50	61%	
		Team 3	33.17	50	66%	
		Team 4	33.82	50	68%	

Since the productivity and efficiency of each team and the supervisor were different in different locations and areas as shown in Table 2, the study further analyzed the efficiency of each team separately and draw a scatter plot diagram using Microsoft Excel to compare their efficiency based on their work area and location. Figure 2 shows the change in the efficiency of the four teams when they worked in different areas. Figure 2 shows that all teams' efficiency was comparatively low while they worked on the second floor. Their performance achieved higher efficiency while working on the first floor. The study then further analyzed what were the factors that affected the team's productivity.

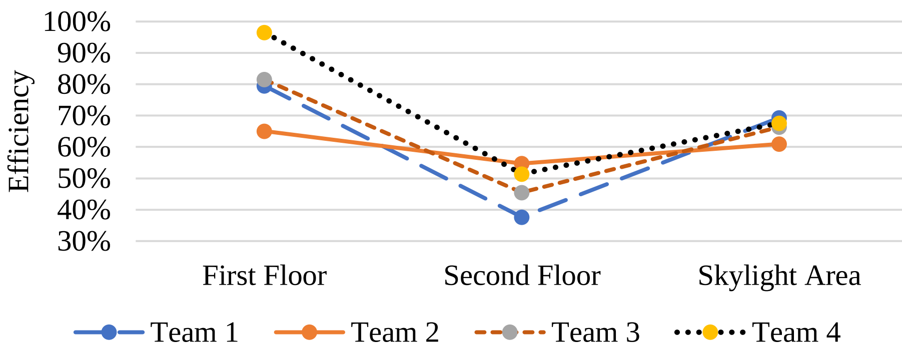

Figure 3. Efficiency of the four sprayer teams

Table 3 shows the factors that affected productivity at the airport project. These factors that caused a loss in the team's productivity were collected from the assistant project manager who was involved in the project to manage the SFRM tasks. Table 3 shows that factors such as adverse weather conditions, sub-trades interference, strict QA/QC procedure, and insufficient materials contributed to productivity losses in all three project locations and areas. For example, adverse weather conditions such as high wind caused SFRM spray task much harder to spray because it was difficult for the sprayer to focus on the area where the SFRM needs to be due to the wind blow.

In addition, the wind caused more waste as it blew SFRM into the air. This led the productivity down than what it was estimated.

Table 3 also shows that some factors were prominent in specific locations and areas to cause productivity loss. For example, the productivity of the four teams had a significant drop in their efficiency when they were working at the second-floor height in the Concourse C (see figure 3). Part of the reasons identified were due to the additional factors such as limited accessibility for material movement and lifting, site congestion, lack of continuity of operation due to priority areas and frequent re-handling of machines and tools. But in comparison for Concourse C, the productivity is high in skylight areas at Main Terminal Building, because these areas were not on high priority lists. Besides, disturbances due to other Subcontractor works and protection of their works were very less. But the factors such as the absence of closed building envelop, perimeter beam that was hard to reach, incompetency of sprayers, and others as shown in Table 3, were the cause of productivity loss in the SFRM task compared to first floor at Concourse A.

Table 3. Factors affecting productivity

Factors	**Locations (Areas)**
Adverse weather conditions	Concourse A (1st floor), Concourse C (2nd floor), MTB (skylight area)
Sub-trades Interference	Concourse A (1st floor), Concourse C (2nd floor), MTB (skylight area)
Inconsistency due to absenteeism	Concourse A (1st floor), Concourse C (2nd floor), MTB (skylight area)
Strict QA/QC procedure	Concourse A (1st floor), Concourse C (2nd floor), MTB (skylight area)
Insufficient materials	Concourse A (1st floor), Concourse C (2nd floor), MTB (skylight area)
Relocation of distribution boards and panel boards	Concourse A (1st floor)
Limited accessibility for material movement and lifting	Concourse C (2nd floor)
Site congestion	Concourse C (2nd floor)
Lack of continuity of operation due to priority areas and frequent re-handling of machine / tools / equipment	Concourse C (2nd floor)
Requirement of high protection	Concourse C (2nd floor)
Absence of closed building envelop	MTB (skylight area)
Perimeter beam that was hard to reach	MTB (skylight area)
Location (high roof) using scissor lift	MTB (skylight area)
Incompetency of sprayers	MTB (skylight area)
Housekeeping and Safety Task Analysis Risk Reduction Talk (STARRT) card	MTB (skylight area)

CONCLUSION

The study analyzed the productivity and efficiency data of the SFRM task at the construction site of the passenger terminal complex of the Hamad International Airport, Qatar. The study analyzed the productivity of the four sprayer teams at the Concourse A, Concourse C, and Main Terminal Building of the airport. The study found that the productivity of each team was not only different among individual teams (where each team consisted of a skilled sprayer, a machine operator, and two helpers) but also was different when they worked at varying floor heights. Besides, each floor height had its challenges, and many factors that were predominant from one area to the other contributed to the loss of productivity. The study found that the efficiency was lowest (47.32%) when the spray team had to work at second-floor heights. Besides, factors such as limited accessibility for material movement and lifting, site congestion, lack of continuity of operation due to priority areas, and frequent re-handling of machines and tools were affecting the productivity of the spray team while they were working at the second-floor heights. Adverse weather conditions, sub-trades interference, inconsistency due to absenteeism, strict QA/QC procedure, and insufficient materials were the factors that contributed to the loss in productivity at all floor heights and all three locations of the airport. Comparatively, Team 4 achieved the highest efficiency among the four teams in this study. Team 4 had 97% efficiency on the first floor in Concourse A. The findings show that although the estimated efficiency was hard to achieve under given conditions, the efficiency of Team 4 on the first floor was very close to the estimated efficiency. The findings show that productivity depends on multiple factors and those factors need to be identified and addressed to minimize the loss of productivity. The company needs high productivity because with high productivity, the company wants to increase profit margin by reducing labor cost. This efficiency would be also the basis for labor and supervisors' evaluation during promotion and salary increment. Further study could be done to evaluate the efficiency of Project managers and Project Engineers based on milestone achievement and maximum area coverage with quality of SFRM application.

ACKNOWLEDGEMENTS

The support of the assistant project manager who provided the data for this study is gratefully acknowledged.

REFERENCES

[1] Bureau of Labor Statistics. "Labor productivity and costs." < http://www.bls.gov/lpc/> Jan. 1, 2016.

[2] A.S. Hanna, C.S. Taylor, and K.T. Sullivan. "Impact of extended overtime on construction labor productivity." J. Constr. Eng. Manage., 131 (6), 734-739, 2005.

[3] E. M. Rojas, and P. Aramvareekul, "Labor productivity drivers and opportunities in the construction industry." J. Manage. Eng., 19(2) 78–82, 2003.

[4] H. S. Park, "Conceptual framework of construction productivity estimation." KSCE J. of Civil Eng., 10(5), 311-317, 2006.

[5] W. Yi and A.P.C. Chan, " Critical review of labor productivity research in construction journals." J. Manage. Eng., 30(2), 214-225, 2014.

[6] H.R. Thomas, and C.T. Mathews, "An analysis of the methods of measuring construction productivity." Austin, TX: Construction Industry Institute, 1985.

[7] M. Liberda, J.Y. Ruwanpura and G. Jergeas, "Construction productivity improvement: A study of human, managerial and external factors." ASCE Construction Research Congress, Hawaii March 2003.

[8] L. Song and S.M. AbouRizk, "Measuring and modeling labor productivity using historical data." J. Constr. Eng. Manage., 134(10), 786-794, 2008.

[9] K. P. Kisi, N. Mani, E.M. Rojas, E.T. Foster. A Case Study on Estimating Optimal Labor Productivity. Construction Research Congress (pp. 1762-1771), 2016.

[10] K. P. Kisi, N. Mani, E.M. Rojas, E.T. Foster. Optimal productivity in labor-intensive construction operations: Pilot study. Journal of Construction Engineering and Management. 2017 Mar 1;143(3):04016107

[11] K. P. Kisi, N. Mani, E.M. Rojas, E.T. Foster. Estimation of optimal productivity in labor-intensive construction operations: Advanced study. Journal of Construction Engineering and Management. 2018 Oct 1;144(10):04018097.

[12] H. R. Thomas and I. Yiakoumis, "Factor model of construction productivity." J. Constr. Eng. Manage, 113(4), 623–639, 1987.

[13] J.D. Borcherding and L.F. Alarcón, "Quantitative effects on construction productivity." Constr. Lawyer (Am. Bar Assoc.), 11 (1), 36–48, 1991.

[14] H.M. Alinaitwe, J.A. Mwakali and B. Hanson, "Factors affecting the productivity of building craftsmen—Studies of Uganda." J. Civil Eng. Manage., 13(3), 169–176, 2007

[15] J. Dai, P.M. Goodrum, and W.F. Maloney, "Construction craft workers ' perceptions of the factors affecting their productivity, J. Constr. Eng. Manage., 135(3), 217–226, 2009.

[16] D. Arditi, "Construction productivity improvement." J. Constr. Eng. Manage., 111(1), 1–14, 1985

[17] A. Enshassi, S. Mohamed, Z. Abu Mustafa, and P. Mayer, "Factors affecting labour productivity in building projects in the Gaza strip." J. Civil Eng. Manage., 13(4), 245–254, 2007.

[18] K. P. Kisi, N. Mani, and E.M. Rojas, Estimating optimal labor productivity: A two-prong strategy. Proc., Construction Research Congress, ASCE, Georgia, 757-766, 2014.

[19] S. AbouRizk, P. Knowles, and U.R. Hermann, "Estimating labor production rates for industrial construction activities." J. Constr. Eng. Manage., 127(6), 502-511, 2001.

[20] R. A. Rivas, J. D.Borcherding, V. González, L. F. Alarcón, "Analysis of factors influencing productivity using craftsmen questionnaires : case study in a chilean construction company." J. Constr. Eng. Manage., 137(4), 312–320, 2011.

[21] Kisi KP, Kayastha R, Shrestha PP. Back Charges in Construction Contract: Case Study of Airport Project. Journal of Legal Affairs and Dispute Resolution in Engineering and Construction. 2020 Aug 1;12(3):05020010.